MINIMISING POST-HARDENING IN PALM OIL/SUNFLOWER OIL SOFT MARGARINE FORMULATION BY OPTIMISING PROCESSING CONDITIONS

MISKANDAR MAT SAHRI* and ZALIHA OMAR*

ABSTRACT

The occurrence of post-hardening in margarine and shortening could lead to serious quality problem resulting in the rejection of the product. Choice of the oils and fats, processing conditions, transportation and storage are some of the common causes of the problem. The effects of processing parameters, obtained from the response surface methodology (RSM) experimental design, on the product consistencies, expressed in yield values (g cm^{-2}), were studied. Simple margarine blend of palm and sunflower oils was used as the model sample. Variation in the process conditions employed in the study produced margarines with significant differences in their consistencies at 5°C, 10°C, 15°C and 20°C. Soft margarine of desired consistency could be produced by varying the throughput speed up to 60 kg hr^{-1}, together with the increase in speed of SSHE1 and SSHE2 at > 500 rpm, while at low throughput <60 kg hr^{-1}, a high pin-rotor speed should be adopted.

Keywords: margarine, hardness, palm oil, crystallisation.

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INTRODUCTION

Margarine and table spreads are composed of oil, fat and water in emulsion form (Andersen and Williams, 1965; Haighton, 1976; Heertje, 1993). Oil and fats are formulated to provide the right oil and fat ratio desirable for the consistency of the final product (Heertje, 1993; Greenwell, 1981). Right blend ratio is determined by the solid fat content (SFC) of the blend at different temperatures. SFC, polymorphic behaviour of the oil and appropriate processing conditions (Heertje, 1993) will further determine the desired end product (Aini and Miskandar, 2007). Margarine can be categorised into table, bakery and pastry margarines, based on their melting behaviours and usages (Mat Sahri *et al*., 2005).

A direct blend formulation of palm-based margarine is still not suitable for table margarine in many countries. Although, palm oil is one of the best fat stocks for producing *trans*-free margarine formulations, post-hardening is still a major problem when it is used at maximum level in these products. According to Duns (1985), palm oil has slow crystallising property and it is the major shortcoming in a margarine production. On the other hand, hydrogenated palm oil could influence other oils with *beta* crystal property to crystallise excellently in *beta prime* form when blended

* Malaysian Palm Oil Board,
6 Persiaran Institusi, Bandar Baru Bangi,
43000 Kajang, Selangor, Malaysia.
E-mail: miskand@mpob.gov.my

together (Yap *et al.,* 1989). Furthermore, blending of hydrogenated oils with other oils will also increase the rate of crystallisation (Moziar *et al.,* 1989) and assists in stabilising the product consistency during storage (Deman and Deman, 1989). Sami *et al.* (2012) conducted crystallisation studies on high and low triacylglycerol (TAG) and reported that a direct blend of palm stearin (IV 36) and palm oil, could only be used at <40% in any margarine formulation. Thus, palm oil is used in the importing countries for margarine making mainly after being interesterified or hydrogenated and blending it with liquid oils, merely to avoid post-hardening and to maintain the margarine in *beta prime* form. Direct blending of palm oil in margarine formulation will become a better choice if post-hardening problem could be solved.

Margarine processing involves a complex process of emulsification, pre-cooling and crystallisation. The emulsion is discharged into the scraped surface heat exchanger (SSHE) or tube cooler by a gear or pressure pump. This is followed by the pin-rotor unit before filling the product into containers at the filling station.

Fats generally require 5-7 min to crystallise in its crystallisation temperature (Haighton, 1976). Therefore, when the fats exit the tube cooler it is only partially crystallised. Thus, it requires time to crystallise followed by further crystal development and growth. In a continuous margarine production, the final crystal development is provided by the pin worker or crystalliser activity (Hui, 1996). Some manufacturers refer to this unit by several names such as pin-rotor, working unit, B-unit or crystalliser unit. Studies by Andersen and Williams (1965) suggest that besides further crystallising the slurry, it also physically breaks up and works on the crystals, thus aiding in texturisation. Heertje (1993) noted a few important aspects of pin-rotor or crystalliser operation, such as that high pin-rotor speeds give rise to soft and overworked products in spreads. Heertje (1993) also reported that different processing parameters, especially churning, which in certain way has similar physical activity to crystalliser operation, could seriously affect the product texture of margarine and butter.

A study on the rate of crystallisation, especially on whether crystal formation should be allowed to occur on the surface of SSHE, was studied by Qin *et al.* (2003) who reported that the liberation of latent heat of crystallisation on the cooling surface of SSHE could increase the heat transfer. The present study is designed to understand the effects of processing conditions on the yield value of a simple margarine blend of palm oil and sunflower oil, and to determine the optimum processing conditions.

MATERIALS AND METHODS

Materials

Refined, bleached and deodorised (RBD) palm stearin (IV=35), sunflower oil and palm olein (IV=58) were purchased from Mewah Oleo Sdn Bhd, Klang, Selangor, Malaysia. Mono and diacylglycerols, as emulsifier, from Danisco (M) Sdn Bhd, Penang, Malaysia. Vacuum dried salt from sundry shop, and water from municipality water supply.

Experimental Methods

Fatty acid composition (FAC), slip melting point (SMP) and SFC were determined following the method of Ainie *et al.* (2005). For the margarine production, the following combination was used: 81.7% fat phase, 0.3% emulsifier, 16% water, and 2.0% salt. Oils and fats were melted in a Memmert drying oven (854 UL 80, Schwabach, Germany) at 65°C, then weighed accordingly for 50 kg production batches. The process flow diagram of the margarine production is shown in *Figure 1*. The emulsifier was first melted in a small portion of the fat blend at a ratio of 1: 4 before adding it to the fat phase. The water phase at 28°C was then added slowly to the oil phase with agitation to form a stable emulsion (Anderson and Williams 1965; Faur, 1996; Hui, 1996; Miskandar *et al.*, 2002; Goli *et al.*, 2009). The emulsion temperature was maintained at 55°C

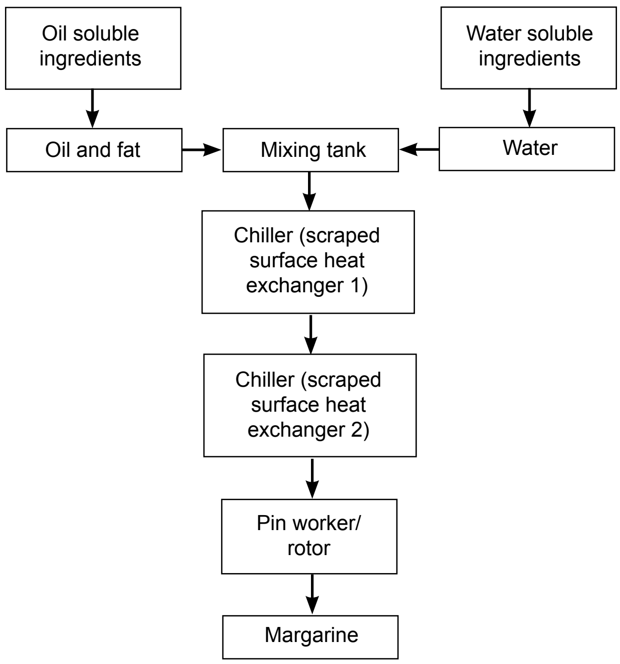

Figure 1. Flow chart of margarine processing.

and held for 15 min in the mixing tank prior to processing in a perfector pilot plant (Gerstenberg and Agger, Copenhagen, Denmark) at the Malaysian Palm Oil Board (MPOB). The tube cooler or SSHE has a volume of 900 ml and scraped cooling surface of 0.063 m^2 areas. Two tube coolers, SSHE1 and SSHE2, were set at standard temperatures for the whole study at 10°C and 20°C, respectively. The pin worker (pin-rotor), with a volume of 3 litres, was set after the SSHE 2. The emulsion was pumped into the SSHE 1 (at throughput rate of 45-65 kg hr^{-1}) where it was rapidly cooled. The rotation speeds of SSHE1, SSHE2 and pin-rotor were 330-750, 330-750 and 0-904 rpm, respectively. The margarine samples were collected at the end of the processing line after the pin-rotor.

The samples for evaluation were placed in 5°C, 10°C and 15°C incubators for 30 days. The consistency was determined by measuring the depth that a needle cone with a specific angle and weight penetrated the margarine from its surface for a given time and at a specific temperature. The cone was dropped freely by the force of gravity. The penetration value is referred to as yield value, g cm^{-2} (Haighton, 1976; Deman *et al*., 1989) using a cone penetrometer (Stanhope-Seta, Surrey, England) with 40° cone, weight of 79.03 g with penetration time of 5 s. The calculation was following the method of Haighton (1976), yield value = $KW/P^{1.6}$, where K=5840, W=79.03+ added weight, and P= mean of penetration readings. Six readings were taken from each sample daily from different sub-samples. Microscopic examination for crystal distribution was measured as described by Miskandar *et al.* (2004), isothermal solid fat content (ISFC) (Miskandar *et al.*,2004). Texture was also analysed to assess the quality of the margarine.

Statistical analyses. Optimisation of the processing condition was by response surface methodology (RSM), statistical package in the Design Expert 6. Model of 21 process conditions including five control conditions with ANOVA at 95% confidence level on samples of three replications was chosen. A few experiments were then picked out to illustrate the variable effects.

RESULTS AND DISCUSSION

Identifying a Representative Blend

The project started with the identification of a good formulation model to be used for the whole study from 14 model blends of palm stearin, palm olein and sunflower oil. A blend containing fatty acids ratio of saturated: monounsaturated: polyunsaturated of 1:1:1 was used in the study. The formulation was selected based on the desired FAC ratio, as well as the SFC, in a similarly desired margarine profile as reported by Saberi *et al.* (2011).

Effects of Throughput on Physical Properties of Palm-based Margarine

The first step in a margarine processing is the emulsification process of the oily and aqueous phases followed by the drive that pushes the emulsion into the machine (the flow of which is referred to as throughput). A study on the effects of throughput speed on the quality of palm oil margarine conducted by Miskandar *et al.* (2002) had shown that crystallisation was effective on low throughput speed due to the reduction in residential time. However, this had to compromise with production capacity (Mat Sahri *et al*., 2005). The current study on the flow rates of the blended fat shows the effects of throughput (*Table 1*). The throughput speed in the process condition TH (65 kg hr^{-1}) was 16% beyond the recommended throughput for the machine, at 56 kg hr^{-1}. At this process condition, the residential time was reduced, which could have also reduced the crystallisation efficiency of the system. The process condition TM (52 kg hr^{-1}) was 7% lower than the recommended throughput while the process condition TL (40 kg hr^{-1}) was 28% lower. The process condition for other parameters in this study are shown in *Table 1.*

Reduction in yield value (YV) was not significant for sample TL produced in low throughput of 40 kg hr^{-1} at 5°C, 10°C, 15°C and 20°C (*Figure 2*). As the throughput was reduced by 26%, crystallisation efficiency of the system has also increased. Crystal packing due to the effective crystallisation did not cause severe increase in YV at 5°C, as shown by the increase of 35.2 g cm^{-2} in every five storage day. Miskandar and Noor Lida (2011) noted that an increase in yield value by 30 g cm^{-2} every five-day storage will produce soft margarine that has good spreadability with no significant post-crystallisation or hardening for nine months. At low throughput speed of 40 kg hr^{-1}, soft margarine had softened during the 15^{th} and 21^{st} day of storage at 10°C. The YV of TL was lower than TM at 15°C and 20°C (*Figure 3*). The excess in residential time had caused overworking of crystal networks in the pin-rotor that led to the formation of extra fine crystals. This condition may have created an increase in temperature due to the latent heat of crystallisation (Miskandar *et al*., 2002), which may in turn caused the low melting TAG to melt leading to the softening of the product. This finding is consistent with that of Saberi *et al.* (2010) in their study on palm-based diacylglycerol where the phenomenon was reportedly more pronounced at high storage temperature (*i.e.* at 15°C and 20°C). However, our results show that the softening of sample TL was not significant at 15°C and 20°C. As the low melting TAG melted, re-crystallisation in uncontrolled condition at 15°C and 20°C had significant effect on crystal formation that might lead to the softening of end product. The study was consistent to a study by Miskandar and Nor Lida (2011) on simple blend of low saturated fat. A great number of fine crystals could have been formed in TL that reduced the risk of crystal agglomeration leading to hardening of margarine.

The YV of sample TM produced in 52 kg hr^{-1} throughput speed at 5°C and 10°C started at the same YV. Sample at 5°C increased to 1700 g cm^{-2} during the 5th and 10th days of storage and reduced steadily to 1500 g cm^{-2} on the 25th day of storage. At 10°C, the sample maintained a constant YV until the 10th day of storage, before declining steadily to 1000 g cm^{-2} on the 20th day of storage (*Figure 3*). The YV at 15°C and 20°C increased by 41.0 and 26.4 g cm^{-2} at every five-day storage, but this increase was not significant.

Crystallisation on process condition TM was expected to be rapid making it possible to produce a completely crystallised product, which might produce high YV due to the development of strong crystal net-workings (Deman and Deman 1984). It is also important to realise that the high speed pin-rotor could break the net-workings and loosen the texture (Miskandar *et al.*, 2004; Mat Sahri *et al.*, 2005). The YV trend of the sample over 25 days storage

TABLE 1. PROCESS CONDITION OF MARGARINE PRODUCTION ON DIFFERENT THROUGHPUT (kg hr^{-1})

Code	Throughput (kg hr^{-1})	SSHE 1 (rpm)	SSHE 2 (rpm)	Pin-rotor (rpm)	Difference in % from recommended throughput
TL	40	750	750	400	-28
TM	52	750	750	400	-7
TH	65	750	750	400	+16

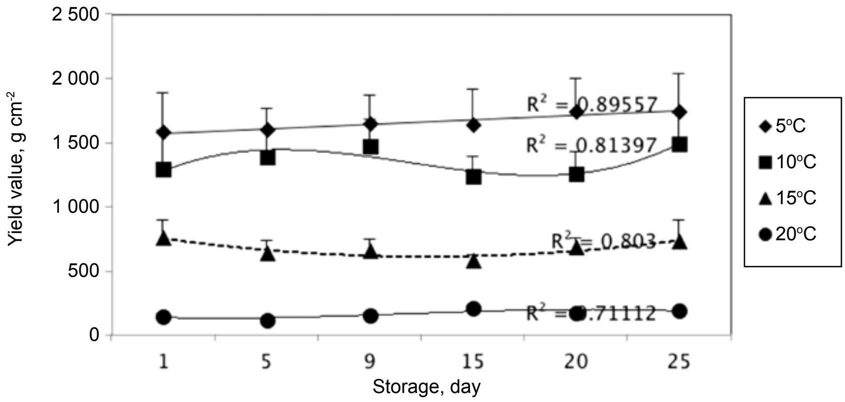

Figure 2. Yield value (g cm^{-2}) of palm-based margarine on process condition TL.

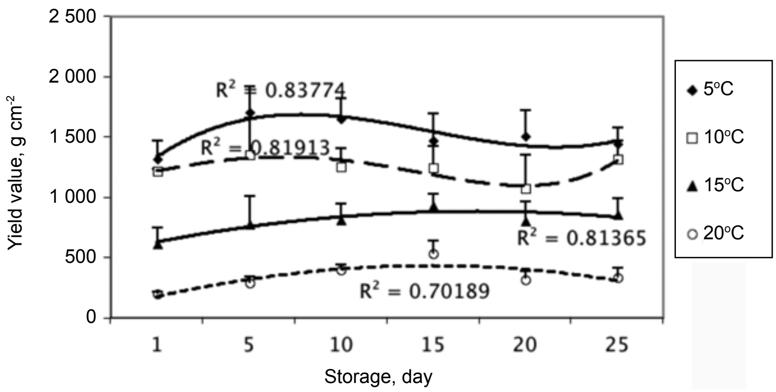

Figure 3. Yield value (g cm^{-2}) of palm-based margarine on process condition TM.

at post-hardening rate of <35 g cm^{-2} indicated the phenomenon of product instability.

The YV of the samples obtained from the process condition TH, on the other hand, increased by 57.6 g cm^{-2} every five days at 5°C, 31.9 g cm^{-2} at 10°C, 26.5 g cm^{-2} at 15°C, and 3.6 g cm^{-2} at 20°C (*Figure 4*). High throughput speed had reduced the residential time in the SSHE, thus reducing the crystallisation efficiency of the margarine. The number of nuclei for a complete crystallisation was not sufficiently created in the pre-crystallisation stage, and therefore, the crystal formed in the product depended only on the limited number of nuclei present. Such a condition favoured the formation of big size crystals resulting to hard product or high YV trend at 5°C. Crystals were not homogenously formed allowing spaces between crystals for melting and re-crystallisation to take place at 10°C and 15°C. When re-crystallisation occurred, crystal matrices reduced their holding capacities over the liquid phase causing it to leak out and the margarine to soften starting from days 15 to 25.

Since the SSHE and pin-rotor speeds were constant, it could be concluded that the properties of the products produced in this study were determined by the throughput speed. Process condition TL apparently had the most stable YV throughout the storage, with yield increment of <35 g cm^{-2} per five storage days at 5°C.

Effects of SSHE1 on Physical Properties of Palm-based Margarine

Process conditions coded as S1L, S1M and S1H were carried out at a constant throughput speed of 52 kg hr^{-2}. The SSHE1 speeds of S1L, S1M and S1H were 330, 750 and 1000 rpm, respectively. The SSHE2 and pin-rotor speeds were kept constant at 750 rpm and 400 rpm, respectively. The temperatures and ingredients remained constant (*Table 2*).

Margarine that was processed in the process condition S1L, operated at 170 rpm below the recommended speed, and stored at 5°C experienced significant hardening after the 10th day of storage at the rate of 127 g cm^{-2} every five days as shown in *Figure 5*. In the case of samples stored at 10°C, they showed significant reduction in post-hardening as compared to those stored at 5°C. Further reduction in post-hardening was very significant at 15°C and 20°C. The results indicated that crystallisation was not efficient on process condition S1L resulting in insufficient formation of nuclei for crystal

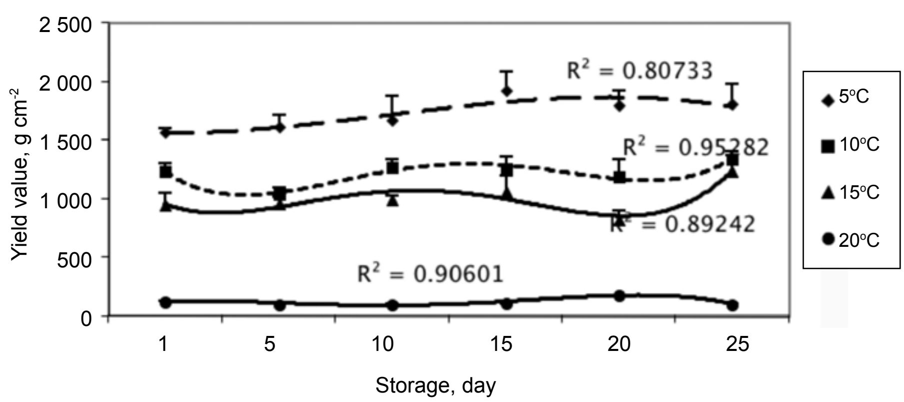

Figure 4. Yield value (g cm^{-2}) of palm-based margarine on process condition TH

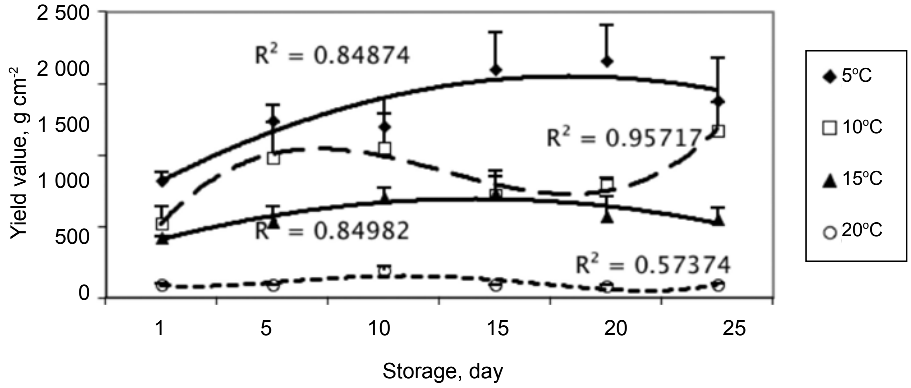

Figure 5. Yield value (g cm^{-2}) of palm-based margarine on process condition S1L.

TABLE 2. PROCESS CONDITION OF MARGARINE PRODUCTION ON DIFFERENT SPEED OF SSHE 1 UNIT

Code	Throughput (kg hr^{-1})	SSHE 1 (rpm)	SSHE 2 (rpm)	Pin- rotor speed (rpm)	Difference in rpm from recommended SSHE1
S1L	52	330	750	400	-170
S1M	52	750	750	400	+250
S1H	52	1 000	750	400	+500

development. This has resulted in the formation of coarse crystals (Faur, 1996). The texture of the sample as shown in *Figure 6* is evidence of brittleness at 5°C during the 25 days of storage and with poor spreadability. Solid fat development as measured by the SFC showed some variability at the first 10 days of storage at all temperatures (*Figure 7*). No significant variations on SFC were observed for all temperatures on the 15th days onwards of the storage time.

Samples prepared in the process condition S1M at 96.4% of its capacity in relation to the cooling surface area of the SSHE and operating at 750 rpm, or, 150% of the recommended rotation speed produced margarines with YV of >1000 g cm^{-2} (*Figure 8*). Pin worker was also operating at an increased rotation speed (400 rpm) in comparison to the recommended speed of 250 rpm (Miskandar *et al*., 2004). As mentioned in the earlier discussion on sample TM, crystallisation on process condition S1M was expected to be very rapid, which might lead to an over-crystallised product and excessively high YV due to the development of strong crystal net-workings. The high speed pin-rotor, on the other hand, would break the net-workings and caused the texture to soften.

Process condition S1H adopted the same flow rate of 52 kg hr^{-1}, SSHE1 speed of 1000 rpm or 200% of the recommended speed, SSHE2 speed of 750 rpm, and pin-rotor speed of 400 rpm. The margarine produced was of good texture with YV of <800 g cm^{-2} during the first day of storage at 5°C (*Figure 9*). There was a significant increase in hardness at 47.8 g cm^{-2} per five storage days during the 25 storage days. The texture was insignificantly changed at temperatures of 10°C, 15°C and 20°C. The straight lines YV gradient indicated that the products were not significantly post-hardened during storage (*Figure 9*). At 10°C, the product softened on the fifth day of storage and returned to normal on the following storage days. The softening of the margarine at -6.7 g cm^{-2} per five storage days is shown by the fluctuating curves. *Figure 10* shows slight SFC reduction at 10°C after the 15th day of storage. However, softening of margarine at -16.3 g cm^{-2} per five storage days occurred at 15°C was insignificant. The product was also very stable

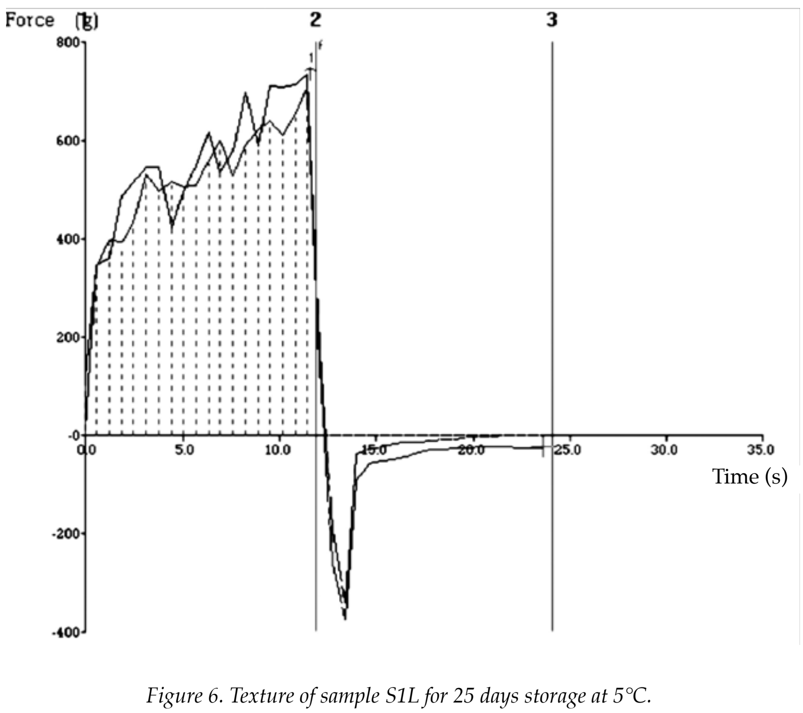

Figure 6. Texture of sample S1L for 25 days storage at 5°C.

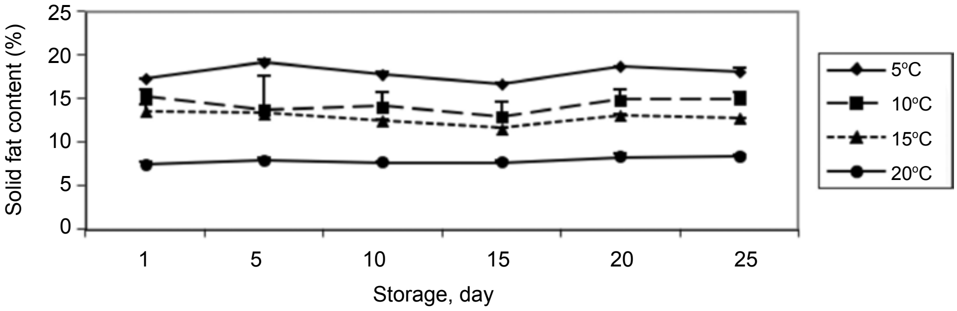

Figure 7. Isothermal solid value of sample S1L for 25 days storage at 5°C, 10°C, 15°C and 20°C.

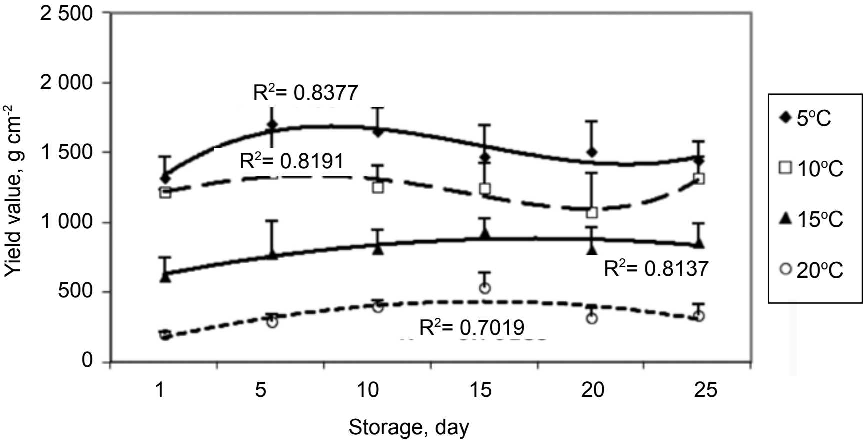

Figure 8. Yield value (g cm^{-2}) of palm-based margarine on process condition S1M.

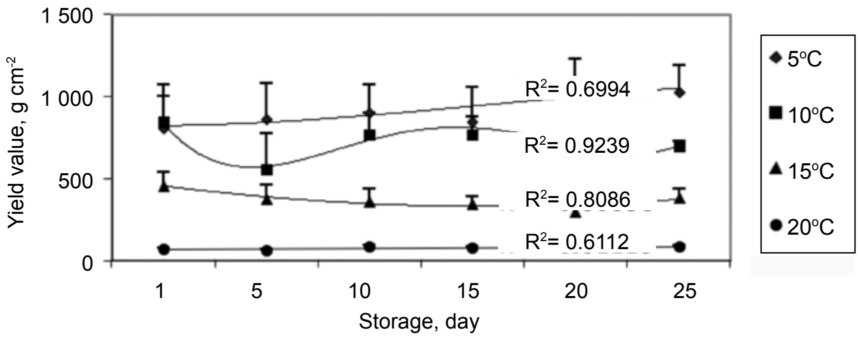

Figure 9. Yield value (g cm^{-2}) of palm-based margarine on process condition S1H.

throughout the storage at 20°C, showing an increase of 4 g cm^{-2} per five storage days. Process condition S1M employed in the study had the same effect as that in TM and PM at 5°C and 10°C.

Effects of Pin-rotor on Physical Properties of Palm-based Margarine

The effect of pin-rotor was studied using processing conditions of HPP (52 kg hr^{-1}), SSHE1 (750 rpm), SSHE2 (750 rpm) and the pin-rotor speeds for process conditions PL, PM and PH of 0 rpm, 400 rpm and 904 rpm, respectively (*Table 3*).

Processing condition PL produced soft and oily margarine at 20°C, but the product was consistent and with good spreadability at 10°C and 15°C. Post-hardening was detected and the margarine was not spreadable at 5°C. According to Haighton (1976) and Goli *et al*. (2009), margarine will not be spreadable when the yield value is >1000 g cm^{-2}. On

TABLE 3. PROCESS CONDITION OF MARGARINE PRODUCTION ON DIFFERENT SPEED OF PIN-ROTOR UNIT

Code	Throughput (kg hr^{-1})	SSHE 1 (rpm)	SSHE 2 (rpm)	Pin-rotor (rpm)	Difference in rpm from recommended pin- rotor
PL	52	750	750	0	-250
PM	52	750	750	400	+150
PH	52	750	750	904	+654

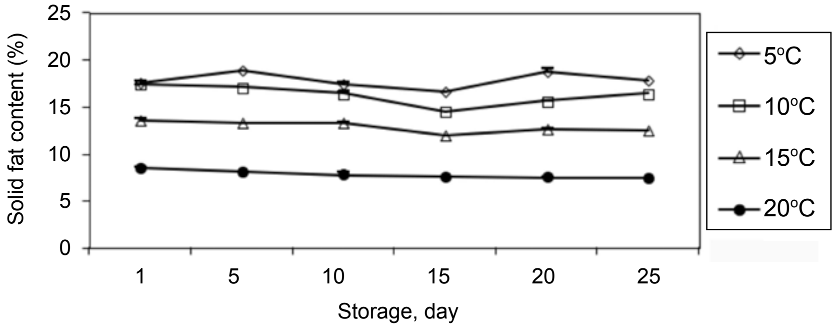

Figure 10. Isothermal solid content of sample S1H for 25 days storage at 5°C,10°C,15°C and 20°C.

the other hand, when the yield value is <200 g cm^{-2}, the product may experience oiling off.

The table margarine processed in condition PL significantly increased in hardness during the storage period of 25 days at 5°C. The YV had continuously increased throughout the storage at YV gradient of 49.3 g cm^{-2} on every five days storage (*Figure 11*).

The result indicated that the speed of SSHE had developed a large amount of crystals that formed networks among them, while the pin-rotor would then break the networks and dispersed them uniformly, thus creating a product that was softer. Without a pin-rotor in the processing line it would leave the crystals in non-homogenous manner forming strong networks that caused the product to harden. *Figure 12* shows the fine crystal packing and crystal agglomeration that influenced product consistency or YV. Solid fat formation caused by the inconsistent crystallisation is shown by the inconsistent SFC of 5°C and 10°C curves as depicted in *Figure 13*. A similar observation was reported by Miskandar and Noor Lida (2011) on the effect of palm stearin of low iodine value on the properties of margarine.

Process condition PM, having similar properties as S1M and TM, produced on pin-rotor speed in between the PL and PH had indicated significant YV results (*Figure 14*). In general, the increase in YV gradient indicated that the degree of post-hardening, as a result of storage time at respective temperatures, was lower than either that of the PL or PH processing conditions. An increase of 30 g cm^{-2} every five days storage at 5°C is considered good, and is expected not to create significant post hardening for 300 storage days (a year) (Haighton, 1976). Sample PM started with high YV of >1500 g cm^{-2}, indicating that the process condition was able to optimise crystallisation to the lag phase, within the residential time in the SSHE. As shown in

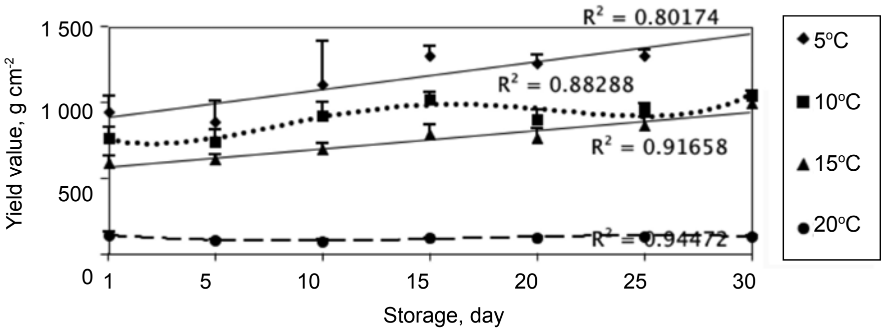

Figure 11. Yield value (g cm^{-2}) of palm-based margarine on process condition PL.

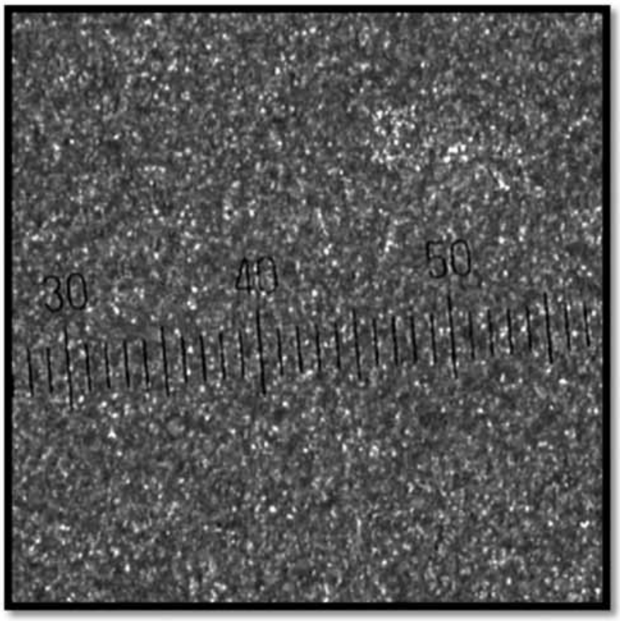

Figure 12. Sample PL at 20°C after 25 days storage. Crystals are closely packed with crystal agglomeration.

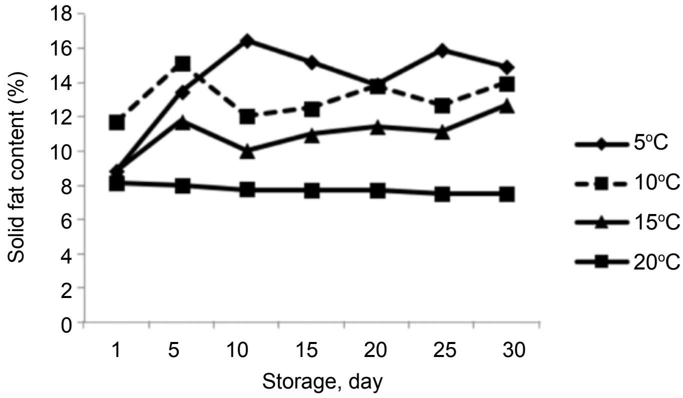

Figure 13. Solid content of Sample PL during 30 days storage, showing inconsistent solid fat content.

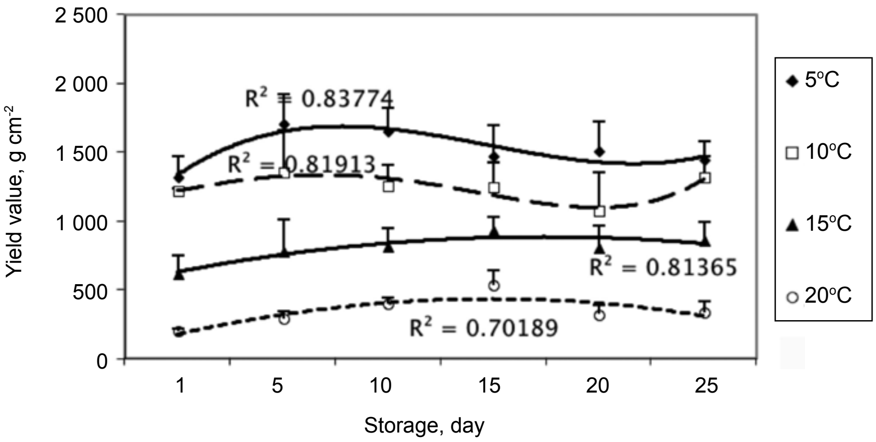

Figure 14. Yield value (g cm^{-2}) of palm-based margarine on process condition PM.

Figure 14, the yield gradient was 19 g cm^{-2} for 10°C, -8 g cm^{-2} for 15°C, and 3.5 g cm^{-2} for 20°C, proving that the process condition could optimise the crystal development during processing, thus reducing the problem of post-hardening during storage. However, the margarine exhibited soft product which could be caused by the product overworking in the pin-rotor.

Crystal size and arrangement of the margarine sample PM under microscopic assessment did not show significant lumpiness or big aggregation of crystals at 20°C (*Figure 15*). Mobilisation of crystals could have occurred that caused destabilisation of emulsion leading to the release of some of the water phase from the crystal matrices, thus formed mixtures of water globule sizes (Mat Sahri *et al.*, 2005). The distribution of the water globules did not cause the product to experience water separation although it experienced softening of the texture during the storage period. Re-melting of crystals with low melting triacylglycerols occurred at 15°C and 20°C, and this created spaces for re-crystallisation that led to crystal packing in the system (Miskandar *et al*., 2002). The circumstances caused an increase in the product hardness as shown by the increase of YV at 15°C and 20°C although not significantly difference over the storage time.

Process condition PH showed significant post-hardening on the margarine throughout the 30 days storage at 5°C, 10°C and 15°C (*Figure 16*), very similar to PL. The YV increase in PH was found to be more significant than PL. Process condition PH, although had started with a consistency of 845 g cm^{-2}, lower than that of PL during the first five storage days, had greater YV gradient of 79 g cm^{-2} every five days storage. Overworking caused by the speed of pin-rotor at 904 rpm, had caused the crystal networking to break, as well as to increase the temperature due to mechanical heating. Increase in temperature had caused low melting TAG to melt (*Figure 17*). Re-crystallisation had produced a more consistent and stable product as shown by a straight line curve at 10°C (*Figure 18*), although some product softening had occurred in the margarine at 20°C.

The study had shown that at a constant SSHE1 and SSHE2 speeds of 750 rpm, pin-rotor speed of 400 rpm could produce margarine with good consistency (Haighton, 1976; Deman *et al*., 1989; Miskandar and Aini, 2010; Goli *et al*., 2009).

Optimisation of Process Condition

The optimum process condition that would yield margarine with the least post-hardening was determined from the yield value results of the 21 processing conditions as designed in the statistical response surface methodology (Saberi *et al*., 2011) (*Table 4*). The process condition model was based on the limitation or constraints as a result of the processing equipment, such as capacity, revolution per minute, temperature and speed, in comparison to product quality (mainly the consistency that is manifested as YV). The results were statistically evaluated on the interrelationships between them.

Although the throughput of the product could be extended to 100 kg hr^{-1}, the process condition limited the use of two SSHEs, SSHE1 and SSHE2 (with scraped cooling surface area of 0.063 m^2) to 900 rpm maximum (with a volume of 900 ml); Yield value increment of 0-10 g cm^{-2} per five storage days was selected in this discussion in view that margarines

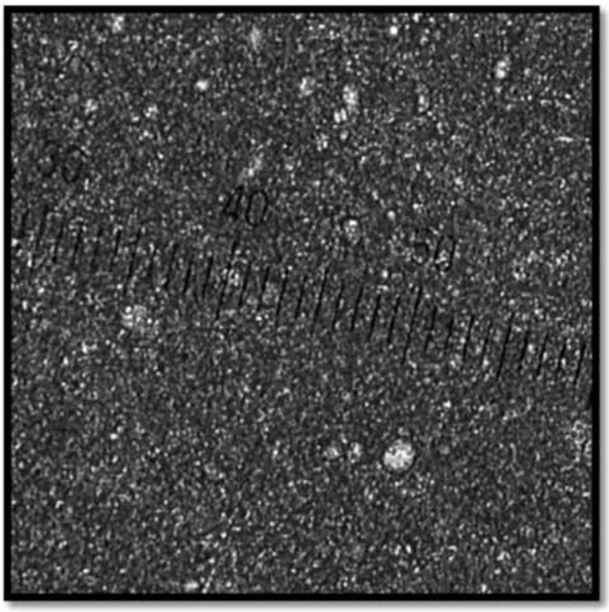

Figure 15. Sample PM at 20°C after 25 days storage. Crystals are less closely packed with water globules.

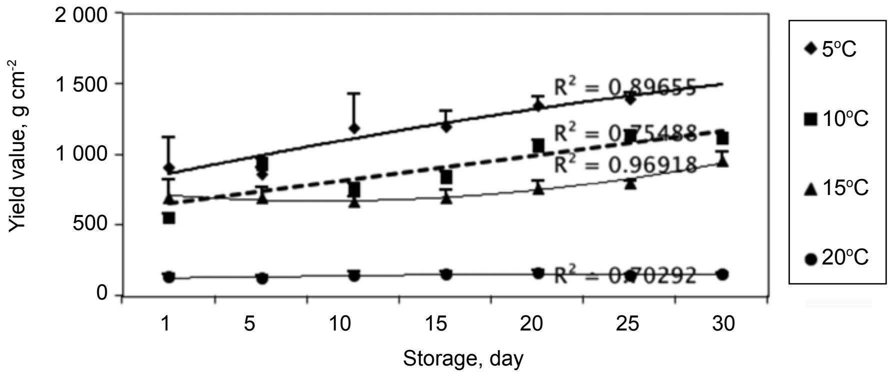

Figure 16. Yield value (g cm^{-2}) of palm-based margarine on process condition PH.

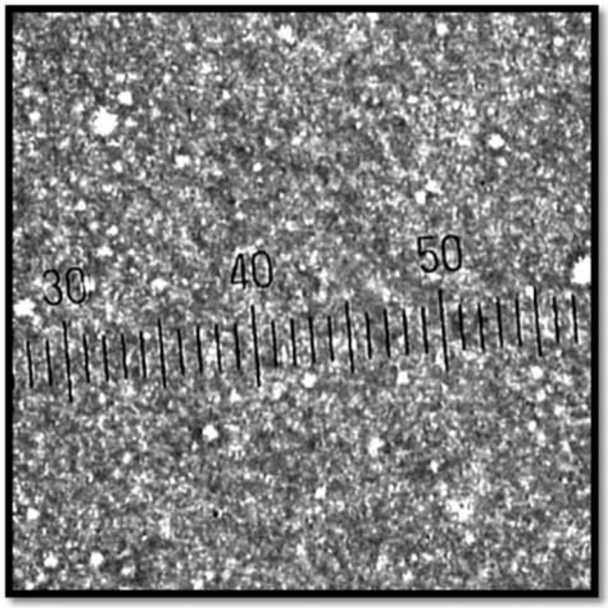

Figure 17. Sample PH at 20ºC after 25 days storage. Crystals are loosely packed with more prominent water globules.

with post-hardening rate of > 12 g cm^{-2} per five storage days will have a consistency increase of > 600 g cm^{-2} within a year. Thus, a soft margarine with a consistency yield value of 400 g cm^{-2} during its first five storage days at 5°C will be expected to have a yield value of 1024 g cm^{-2} after one year of storage.

The interactions between parameters affecting the product consistency are shown graphically in *Figures 19a* to *19c*. The effects of the speed of SSHE 1 and throughput on the yield value of margarine, while maintaining the speed of SSHE2 and pin-rotor constant, is shown in *Figure 19a*, the graph indicates that the speed of the SSHE1 should be > 500 rpm and to be gradually increased with the increase of the flow rate in order to produce margarine with a constantly low increase in yield value per five storage days.

The effects of throughput and speed of SSHE2, while SSHE1 and pin-rotor are maintained constant, is shown in *Figure 19b*. The graph shows that as the flow rate is increased, the speed of SSHE2 should be maintained constant throughout the processing in order to produce the margarine with a low increasing rate of YV g cm^{-2} per five storage days.

The effects of throughput and speed of pin-rotor, while SSHE1 and SSHE2 are maintained constant is shown in *Figure 19c*. Here, it shows that in order to produce a margarine with low increment rate of YV (g cm^{-2}), a low flow rate, combined with a high pin-rotor speed, could be adopted in the process condition. This also means that in any increase in the emulsion flow rate, there should be no further increase in the speed of pin-rotor.

Margarines with low YV (rate of YV increase in g cm^{-2} per five storage days) could be obtained

TABLE 4. MODEL OF 21 PROCESS CONDITIONS INCLUDING FIVE CENTRAL POINTS

Code	Flow (kg hr^{-1})	SSHE 1 (rpm)	SSHE2 (rpm)	pin-rotor (rpm)
933	52	750	750	0
934	52	750	750	904
937	65	750	750	400
938	45	1 000	1 000	700
968	40	750	750	400
969	52	750	750	400
983	45	500	1 000	100
984	45	1 000	500	700
987	52	750	330	400
988	52	750	750	400
995	60	1 000	500	100
1003	52	750	750	400
1005	52	330	750	400
1004	52	1 000	750	400
1016	45	500	500	100
1013	52	750	750	400
1015	60	500	500	700
1014	52	750	750	400
1038	52	750	1 000	400
1039	60	500	1 000	700
1040	60	1 000	1 000	100

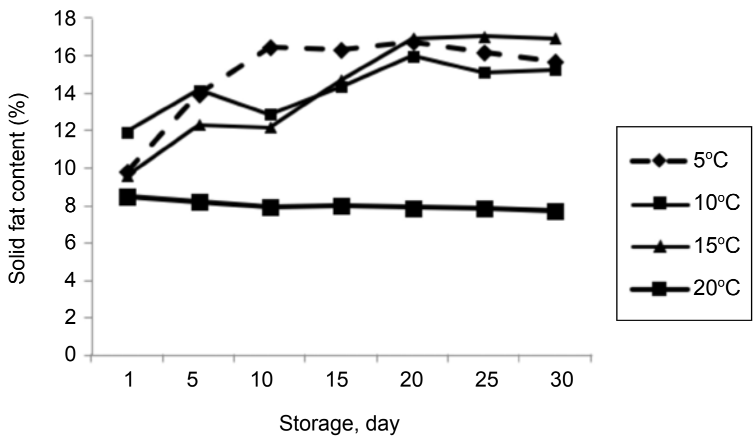

Figure 18. Solid content of Sample PH during 30 days storage, showing consistent solid content after the fifth day of storage.

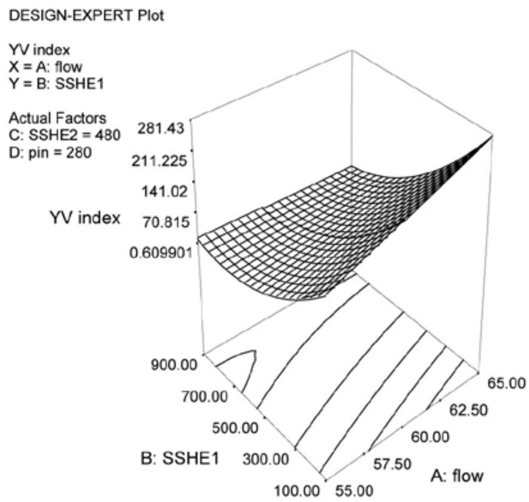

Figure 19a. The effects of throughput and SSHE1 on the rate of YV, while maintaining the SSHE2 and pin-rotor constant.

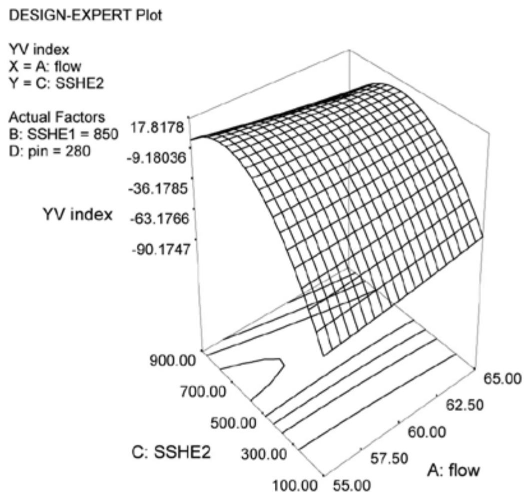

Figure 19b. The effects of throughput and SSHE2 on the rate of YV, while maintaining the SSHE1 and pin-rotor constant.

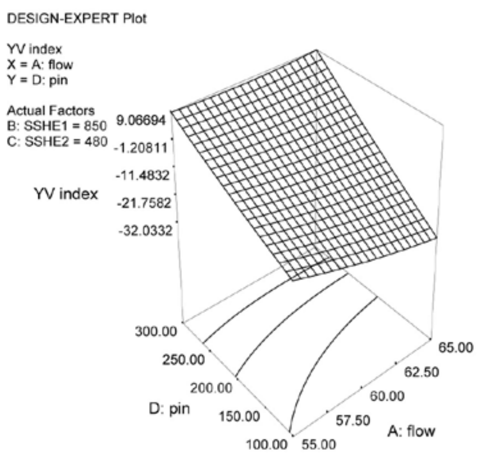

Figure 19c. The effects of throughput and pin-rotor on the rate of yield value, while maintaining the SSHE1 and SSHE2 constant.

during storage when optimum process condition is followed. Process parameters have their limitations or constraints that affect the final product quality. Selected solutions for the process conditions from the experimental design have been identified and shown to be able to minimise post-crystallisation during storage. With respect to the formulation used in this study, the consistencies are between 1000-1800 g cm^{-2} at 5°C and 10°C. Thus, for producing softer products, formulations with low SFC profiles should be selected.

CONCLUSION

Soft margarine of similar formulation could perform in different physical properties by varying the manufacturing process condition. Process condition TL apparently had the most stable YV throughout the storage, with yield increment of <35 g cm^{-2} per five storage days at 5°C. Process condition S1M on the other hand had the same effect as that in TM and PM at 5°C and 10°C. At a constant SSHE1 and SSHE2 speeds of 750 rpm and pin-rotor speed of 400 rpm could produce margarine with good consistency. Generally soft margarine of desired consistency could be produced by varying the throughput speed <60 kg hr^{-1}, together with the increase in the speeds of SSHE1 and SSHE2 at > 500 rpm and a high pin-rotor speed.

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